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EDITORIAL

Model-driven data-intensive Enterprise Information Systems

Introduction

The special issue is motivated by the extensive growth of interest for embedding so-called Big Data, Wireless Sensor Networks (WSN), Cyber-Physical Systems (CPS) and Internet-of-Things (IoT) capabilities into traditional Enterprise Information Systems (EIS) architectures. In the EIS world, those new capabilities would significantly expand the scope of planning and monitoring to end-to-end processes, encompassing full supply chain, while also including new stakeholders or events having the impact to these processes.

Networks of physical objects with sensing, data collection, transmission and actuation capabilities, and vast endpoints in the cloud, offering large amounts of heterogeneous data, become increasingly important enterprise resources and sources for fundamental analytics. The large number of identifiable devices, used also on a sharing basis, is expected to become a commodity in the future, also providing a technology tool for emergence of so-called 'sensing enterprise' (Noran, Romero, and Zdravković 2014).

Technology stack seem to be already there, with large number of cloud-based IoT platforms, offering connectivity, storage, analytics and visualization in a secure way and at scale. However, critical issues still remain open.

First, such diversity will pose tremendous challenges related to the interoperability issues. The new technological landscape, provided by the Future Internet systems will thus establish interoperability problems as critical and possibly consider the interoperability as an inherent capability of the future information systems.

Second, while the interoperability is self-obvious challenge, implementation problem is inherited from the traditional EISs and even multiplied when considering significantly increased complexity of the EISs operating in IoT world. In order to capitalize on the technological trend of data sources commoditization and thus start evolving from digital to sensing enterprises, existing EISs need to change. Such change may imply any of the following: complete EIS re-design and re-deployment, full integration with off-the-shelf tools or empowering existing systems with specific interoperability infrastructures.

The objective of this Special Issue is to present state-of-the-art research in using Model-Driven Engineering approaches, techniques, tools and practices to overcome issues arising from transition from traditional process-focused to data-intensive EIS, where this transition is facilitated by any of the three above mentioned approaches. The Issue is also expected to highlight new challenges and opportunities, related to the new role of EISs in the 'datafied' world we are living in, today.

Discussion

Model Driven Engineering (MDE) is a software development approach in which abstract models of software systems are systematically transformed to their specific implementations. MDE is driven and motivated by the growing complexity of software, which additionally increases the gap between the problem-level software abstractions (e.g. requirements) and its implementation. Today, MDE approaches and practices are commonly addressed by using a Model Driven Architecture (MDA).

Different approaches of using MDE are notable at different levels of EIS implementation, namely, system design (and requirements engineering as its vital part) and development. Furthermore, MDE has shown to be useful also for considering different architectural viewpoints to the system, by designing it around different focal artefacts, such as interaction and process. While the role of MDE in systems based on relational data structures is quite clear, this is not the case in data-intensive systems which are often based on loosely structured and unstructured data. Unveiling their hidden structures and correlating those structures with existing data models are of crucial importance for the effective implementation of those systems.

System design

At the design level, widely accepted MDE standards – UML/SysML languages and tools are often being used, although new modelling paradigms have started to emerge. Design-level use of MDE standards is important in development of very complex distributed systems, which are difficult to maintain due to possible interoperability problems. Examples of solutions to the design of such complex systems are provided in the domain of development healthcare systems (Dimovski et al. 2018) and manufacturing systems (Liao et al. 2018). Liao et al. (2018) proposed the approach of combining the specific design (holonic) approach with using new modelling paradigm, convenient for the analysis of interoperability issues, namely Notification-Oriented Paradigm (NOP).

Requirements engineering plays important role and has large impact to the effectiveness of data-intensive systems design. Requirements elicitation is considered as one of the critical factors for successful systems design as it is expected to facilitate reconciliation of the functional and implementation visions of one system, from two quite different and sometimes contradicting viewpoints – customers and developers. Formal representation of those requirements reduces or completely removes bias and ambiguity from their definition and even facilitates reasoning and effective mining over the systems representation, thus enabling detection of incomplete or contradicting definitions (Diamantopoulos and Symeonidis 2018). However, the effectiveness of well-formed requirements can be preserved only if they are continuously maintained throughout whole system engineering process. This is particularly difficult in data-intensive systems due to the dynamics of their environment, often unstructured data, etc. One of the proposed solutions to maintenance related problems is based on data-driven software systems, associated with user interfaces corresponding to used data structures, a software change request service and initial change impact set (Stojanov, Dobrilović, and Stojanov 2018).

Transition to online business models by enterprises assumes a significant shift in considering the requirements related to security issues. Security-by-design is a novel systems engineering paradigm which aims to address security issues in a full engineering lifecycle (Zolotas, Chatzdimitriou, and Symeonidis 2018).

System development

At the development level, researchers and practitioners use more implicit formalisms, namely the Domain Specific Languages (DSL), to enable even domain experts to develop specific components of data-intensive EISs.

For example, DSLs can be used for development of intelligent agents in Multi-Agent Systems (MAS) and the development of micro-services. Both development paradigms are quite relevant for the design and development of data-intensive EIS.

Micro-services play an important role in data-intensive EIS and especially in IoT, as implementation of the servitization and componentization principles in its design and development. Using DSL in their development can significantly increase the reliability and quality of micro-services, as well as reduce the redundancies in their design (Terzić et al. 2018).

Centralized architectures are proven inefficient in very complex data-intensive (especially IoT) environments, due to a lack of flexibility, especially from the scaling perspective. Peer-to-peer architectures aim to resolve this problem and Multi-Agent System paradigm is often used as a design approach. However, interoperability and platform dependence still remain difficult issues in implementing MAS. It is often addressed by implementing the specific DSLs (Sredojević, Vidaković, and Ivanović 2018).

While interoperability is the most crucial functional requirement in a conceptual systems design, security is major non-functional one. Most often, security-related requirements are considered only at infrastructural or design level, while their actual implementation remains in a black box. RESTsec facilitates rapid security requirements modelling, based on the desired access control policy and generation of the enterprise services, security infrastructure and actual code (Zolotas, Chatzdimitriou, and Symeonidis 2018).

Interaction modelling

To facilitate interaction modelling in a heterogeneous environment and thus, to address the resolution of interoperability problem, many researches rely on the formal models, namely ontologies at different levels of system abstraction (Dimovski et al. 2018) (Liao et al. 2018) (Diamantopoulos and Symeonidis 2018). The expressivity of formal models, combined with a range of available domain ontologies has shown useful also in designing experiments and respective automatic code generation for test-beds, as a powerful alternative to the relevant DSL languages and especially complex experiment configuration tools (Jelenković, Tošić, and Nejković 2018).

Modelling interactions have tremendous impact to design of peer-to-peer environments, such as MAS. Use of MAS in enterprise is significantly constrained by the level of autonomy of the intelligent agents. Reliability of such enterprise MAS infrastructures is questionable due to the fact that intelligent agents often interact and/or make decisions based on incomplete knowledge. In order to increase the reliability, negotiation model is being developed and implemented in a platform which aims to increase the quality of interactions in collaborative working environments (Cretan et al. 2018).

Process modelling

A process model perspective is widely used discourse to understand the inner workings of the complex EIS, for the purpose of its analysis, optimization and/or re-engineering (Dimovski et al. 2018). However, this perspective is not commonly used in WSN, CPS and IoT systems. In such systems, the processes are defined in ad-hoc manner, which could create different issues, for example in systems re-engineering. The first of the research problems related to this issue is lack of understanding of underlying process structures and it could be addressed by implementing process discovery and mining from data streams (Moisescu et al. 2018).

New architectural trends in designing EISs, especially in big data world are posing new challenges. With appearance of peer-to-peer interoperability approaches and increasing trend of servitization of IT functionalities, the design of EIS is more difficult to conform to the unique process model. Thus, this model needs to be continuously validated and repaired in cases where it does not correspond anymore to the realities of EIS operation. Process repair is a specialization of process mining approach in which the process model is changed based on the analysis of the event logs from EIS or actual recorded activities that took place. Choice structures method can be used to repair Petri-net process representations, while taking into account both precision and simplicity (Qi et al. 2018).

Data structures

With introducing big data in enterprise, EIS landscape now needs to consider sources of loosely structured or unstructured data, residing in distributed, big data repositories, such as Hadoop. In order to unlock the potential for using this data, especially for analytical purposes, those loose structures need to be mapped to relational models of the core EISs. In fact, in a big data world, data is typically unstructured and models have descriptive rather than prescriptive role. NoSQL databases addresses challenges related to non-functional requirements, such as performance, availability and scalability, while SQL models consider information design.

Relational data can be migrated to NoSQL storage or relational and non-relational databases can be integrated, but both approaches imply significant effort and time.

Schema on read modelling approach combines read modelling and data virtualization techniques to achieve integration of structured and unstructured data (Janković et al. 2018). Instead of integrating both sources, Bjeladinović (2018) suggest that sometimes there is a strong need for simultaneous use of SQL and NoSQL databases. Hybrid SQL/NoSQL databases are strong candidate for solution of the above problems. The approach in their development is proposed (Bjeladinović 2018) and it also encompasses requirements analysis and design and redesign processes. Zečević et al. (2018) take one step further and besides extracting data structures from data streams, they consider using this structure as a formal, executable specification for a specific target platform.

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